Indian Institute of Technology Kanpur

AE451A

Experiments in Aerospace Engineering - III

Experiment No. 10

PERFORMANCE ANALYSIS OF A TURBOJET ENGINE

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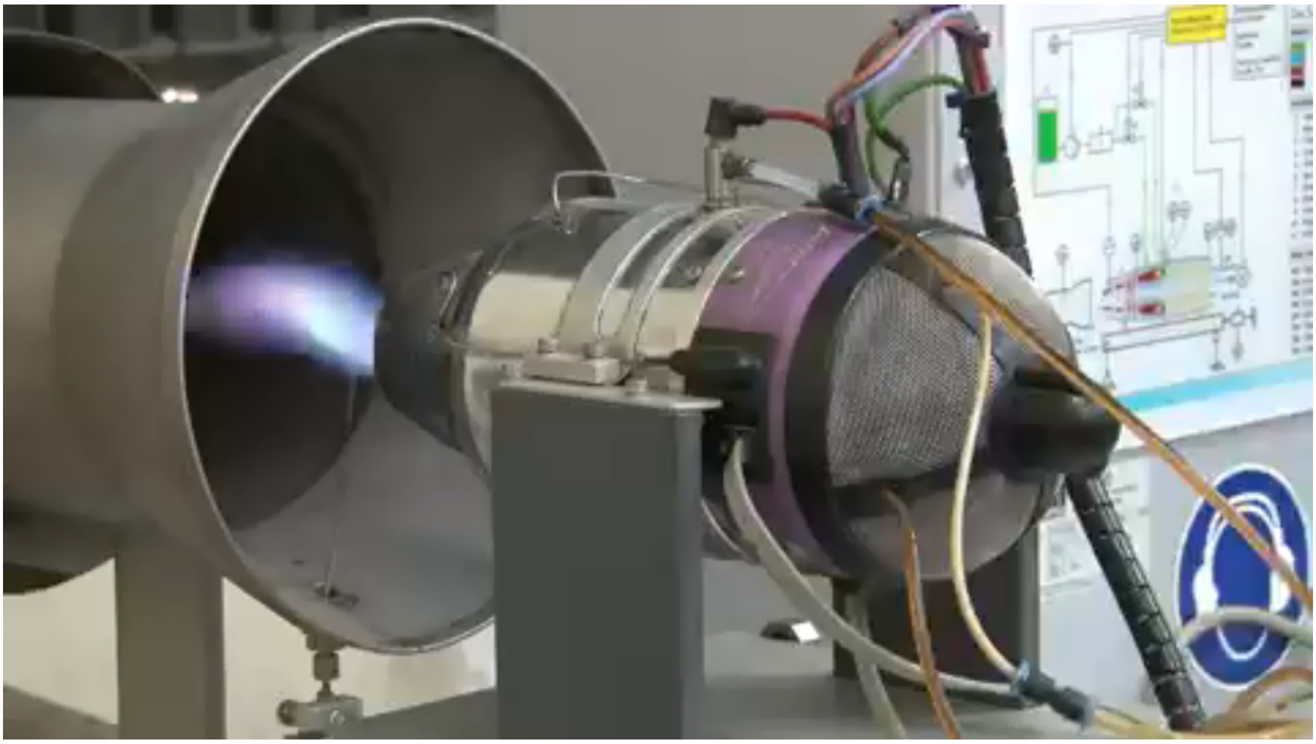
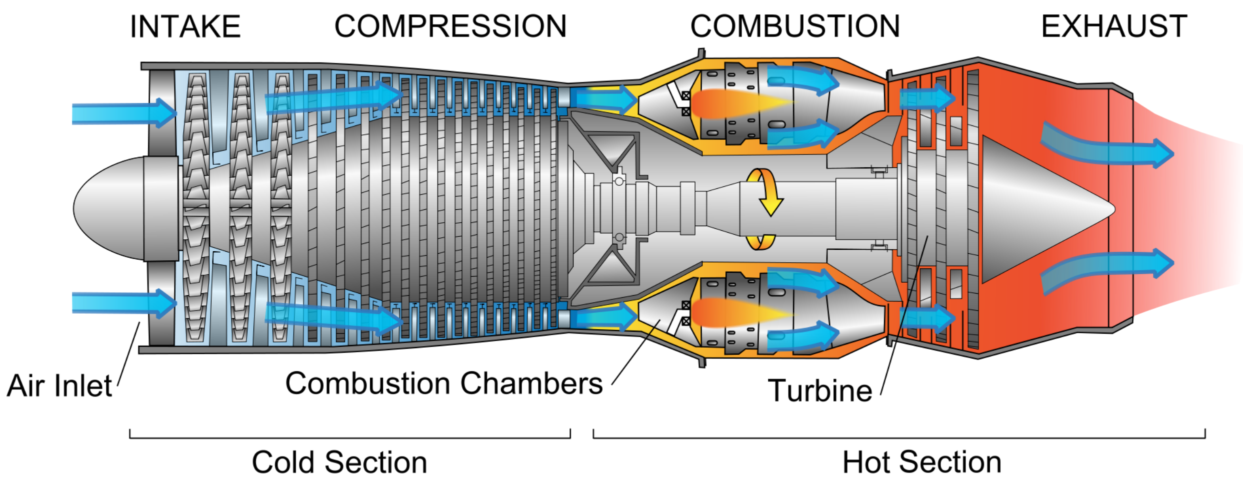
1. Objective

The objective is to understand the operation and evaluate the performance of a turbojet engine, at different operating conditions.

2. Introduction and theory





The ambient air is drawn in, and is first brought to a higher pressure in the single-stage radial compressor. In the downstream combustion chamber, fuel is added to the compressed air and the resulting mixture is combusted. The temperature and flow velocity of the gas increases. The gas flows out of the combustion chamber into the

single-stage axial turbine and discharges a portion of its energy to the turbine. This turbine drives the compressor. In the propelling nozzle, the partially expanded and cooled gas expands to ambient atmospheric pressure and the gas accelerates to high speeds. The high-speed gas outflow generates the thrust. In order to reduce the outlet temperature, the exhaust gas stream is mixed with the ambient air in a mixing pipe. The gas turbine is started fully automatically with the aid of an electric starter. Between the compressor and the turbine is the annular combustion chamber. The movable platform, with a force sensor, enables measurement of the thrust.
The speed, temperatures, static pressures and mass flow rates of the air and fuel are recorded using appropriate sensors. The measured values can be read on digital displays.

3. Equipment's

- turbojet engine
- thermocouples
- ressure sensor
- spark plug
- load cell
- fuel
- control panel

4. Checklist Before Starting

1. Check fuel lines for air bubbles or blockages.
2. Check that fuel tank vent is unobstructed
3. Make sure there is sufficient fuel for a complete test run.
4. Set throttle trim and turbine (Aux channel) mode switch to OFF
5. Lift the turbine desk at the front end to enable residual fuel on turbine to come out.

5. Procedure

1. Set the throttle trim switch to ON and set throttle lever to IDLE (minimum).
2. Switch on the ET796 at the master switch and set turbine (Aux channel) to RUN.
3. The 3 LED lights will light up in sequence. Start the automatic starting process by fully opening the throttle lever.
4. The starter motor brings the turbine to starting speed. The glow plug is activated and auxiliary fuel is given for ignition. Ignition is identified by a rise in temperatures seen on the display panel.
5. After a short time, bring the throttle to IDLE position and being the experiment.
6. Slowly vary the rpm of the engine from 40,000 to 100,000, in steps of 10,000 rpm.
7. At each step, record all the parameters displayed in the digital display panel. After reaching 100,000 rpm and recording all the required data the experiment is

complete.
8. After completing the experiment, turn off the turbine (Aux channel) mode switch to AUTO OFF. To cool the turbine, the starter motor continues running until a temperature of below 100 oC is reached. Once the turbine has cooled down, switch the turbine (Aux channel) mode switch to OFF.

6. Calculation

Units Conversion and other assumptions:

1. Mass flow rate

$$m_a(\frac{kg}{s}) = \frac{m_a(\frac{Ltr}{s})\times\rho_{ambient}}{1000} \tag{1}$$

$$m_f(\frac{kg}{s}) = \frac{m_f(\frac{Ltr}{hr})\times\rho_{fuel}}{3600*1000} \tag{2}$$

Where, $\rho_{air} = 1.2\ kg/m3$ and $\rho_{fuel} = 840\ kg/m3$

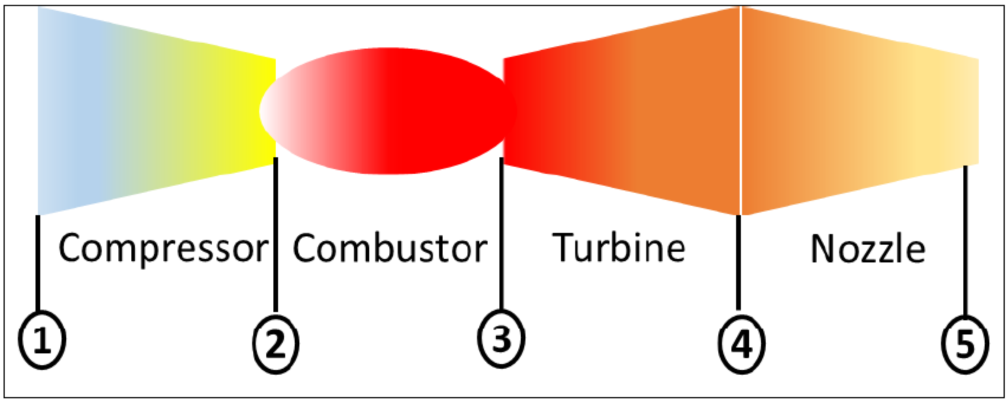
2. Temprature

$$T(K) = T(^\circ C) + 273 \tag{3}$$

3. Pressure

$$Pressure(kPa) = Pressure(bar)\times 100 \tag{4}$$

$\gamma_{cold} = 1.4$ and $\gamma_{hot} = 1.33$
$C_{P_{cold}} = 1005\ \frac{J}{kg.K}$ and $C_{P_{hot}} = 1150\ \frac{J}{kg.K}$



Ambient Conditions:

Pressure (P_{01}) = measured from barometer in lab or assume **101.325 kPa**

Temperature (T_{01}) (K) = measured from thermometer in lab = **287 K**

Compressor Pressure Ratio (P02/P01):

Compressor Exit Pressure (P02) (kPa) = P01 + [P02 (bar)× 100]

Since the measured value is gauge pressure, we add ambient pressure to get absolute pressure. Also, convert from bar to kPa by

multiplying 100.

Knowing P02 and P01 (P01 is the same as Pambient), we can now estimate the compressor pressure ratio, P02/P01.

Combustor Exit Pressure (P03) (kPa) = P02 × 0.95

Assuming that there is a 5% pressure loss in the combustor, we can estimate combustor exit pressure from the compressor exit

pressure.

Compressor Efficiency (η_c):

$$\eta_c = \frac{\left(\frac{P_{02}}{P_{01}}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} - 1}{\frac{T_{02}}{T_{01}} - 1} \tag{5}$$

Global Equivalence ratio (ϕ_g):

$$Global\ Equivalence\ Ratio = \frac{Actual(\frac{Fuel}{Air})}{Stoichiometric(\frac{Fuel}{Air})} \quad (6)$$

$Actual(\frac{Fuel}{Air}) = \frac{m_f}{m_a}$ and $Stoichiometric(\frac{air}{fuel}) = 15$ for ATF.

It can be calculated using the stoichiometric equation for the combustion of ATF (use C12H26 to simulate ATF composition).

Specific Thrust:

$$SpecificThrust = \frac{Thrust(Newtons)}{Total\ Intake\ Air\ Flow(\frac{kg}{s})} \quad (7)$$

Thrust Specific Fuel Consumption (TSFC):

$$TSFC = \frac{Fuel\ Consumption(\frac{kg}{s})}{Thrust(Newtons)} \quad (8)$$

Mach Number

$$\begin{gathered} exit\ velocity(U_e) = \frac{Thrust}{\dot{m}_a + \dot{m}_f} \\ speed\ of\ sound(a) = \sqrt{\gamma_{hot} * R * T_{04}} \\ M = U_e/a \end{gathered} \quad (9)$$

7. Data analysis

Data Table (Converted Units)

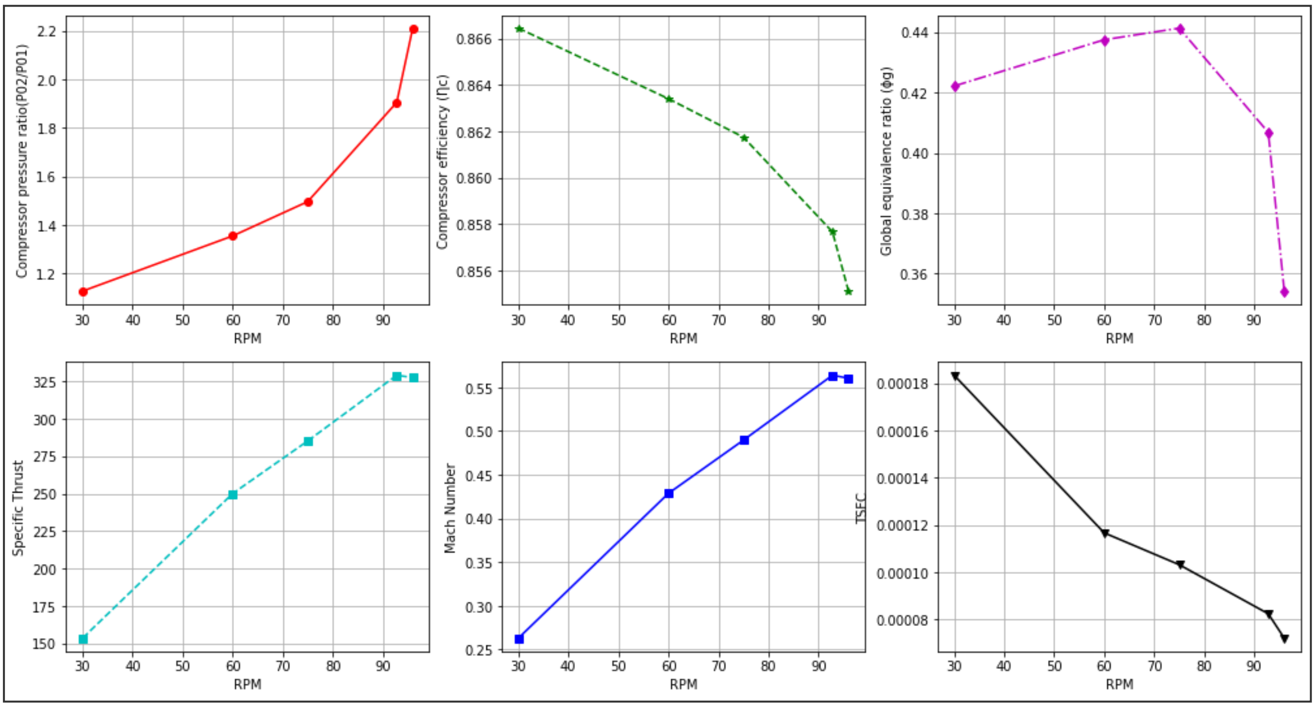
	RPM*1000/min	Compressor Inlet Temperature (K)	Compressor Inlet absolute Pressure (kPa)	Compressor Exit Temerature (K)	Combustion Chamber Exit Temperature (K)	Combstion Chamber Exit Gauge Pressure (kPa)	Turbine Exit Temperature (K)	Fuel Flow Rate (kg/s)	Air Flow Rate (kg/s)	Thrust (N)
0	30.0	287	101.325	297	1127	6.0	844	0.001283	0.0456	7
1	60.0	287	101.325	313	1117	19.0	841	0.002100	0.0720	18
2	75.0	287	101.325	322	1123	36.0	838	0.002683	0.0912	26
3	92.8	287	101.325	345	1150	62.0	845	0.003710	0.1368	45
4	96.0	287	101.325	360	1186	77.0	853	0.003967	0.1680	55

Parameters Table

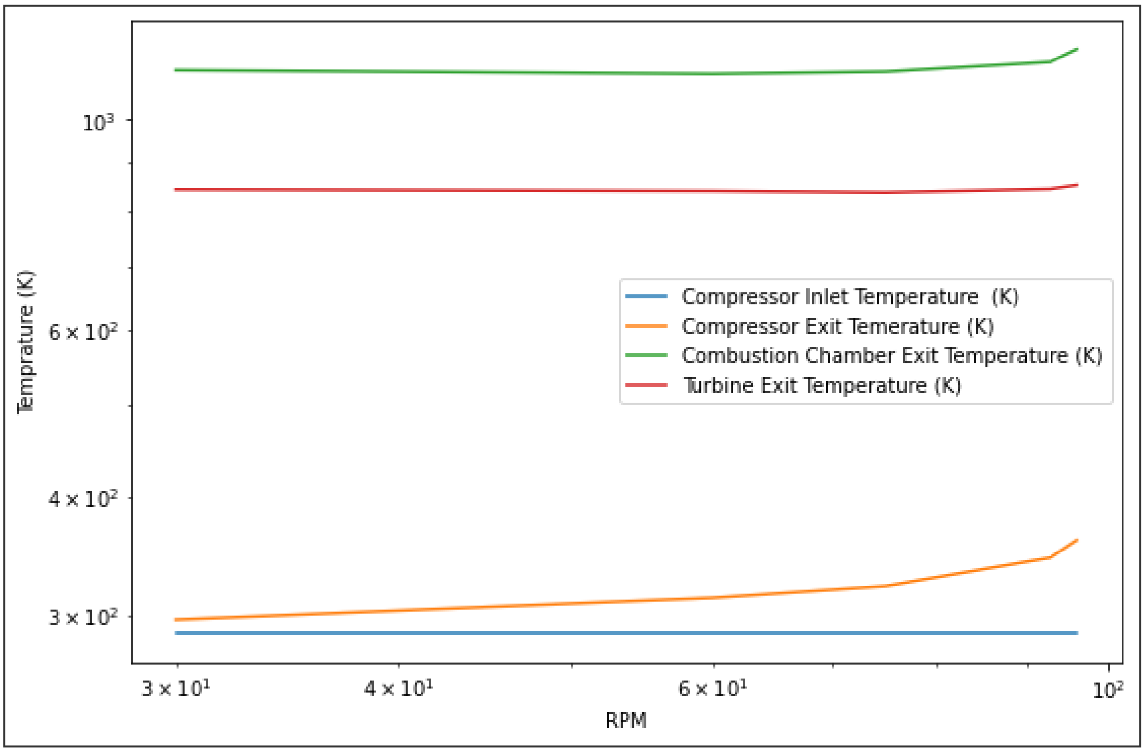
	RPM*1000/min	Compressor pressure ratio(P02/P01)	Compressor efficiency (Ƞc)	Global equivalence ratio (ϕg)	Specific thrust	TSFC	Mach No.
0	30.0	1.127356	0.866456	0.422149	153.508772	0.000183	0.263052
1	60.0	1.354623	0.863414	0.437500	250.000000	0.000117	0.428736
2	75.0	1.495922	0.861755	0.441338	285.087719	0.000103	0.489662
3	92.8	1.904497	0.857671	0.406798	328.947368	0.000082	0.563910
4	96.0	2.210406	0.855120	0.354167	327.380952	0.000072	0.560502

8. Results and discussion

Parameters Plots



Temprature trends with RPM



9.Precautions

1. Do not operate unless a lab technician or teaching assistant is present.
2. NEVER exceed the maximum RPM limit of 110,000 RPM.
3. While increasing RPM, do so slowly, in the stipulated increments only.
4. During the experiment, the gas turbine components will get very hot. Do not touch any part of the gas turbine during the experiment.
5. Stay well away from the exhaust of the gas turbine during operation.

10. References

- Jupyter Notebook of data analysis